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Assessment of Injury Rates Associated with Road Barrier Collision

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Abstract

This paper presents a study aimed at quantifying and comparing the risk of personal injuries associated with road barrier collisions. Documented data from actual barrier collisions, including post-impact collisions, in Sweden between 2005 and 2008 were analyzed. The analyses were based on the injury classification made by healthcare services. The injury rates, measured in number of injuries per vehicle kilometer travelled, were calculated for the different injury classes as a basis for evaluating barrier performance. The results show that the rate of injuries was higher due to collisions with flexible barrier systems, such as cable barrier, than with other semi-rigid and rigid barrier system, such as w-beam and concrete barriers. This result might be explained by a high rate of post-impact events, such as post-impact collisions, roll-overs and over-rides, associated with the placement and mechanical properties of the cable barriers. The study also showed a considerable difference in injury classifications made by the police and the healthcare services, as well as a considerable under-reporting of barrier collisions by the police.

Keywords: road barrier collision; road accident injuries; cable barrier collisions.

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1. Introduction

The life-cycle costs for road barriers, are seldom considered during the initial selection of barrier types due to limited information regarding maintenance and socio-economic costs (Karim 2008; Karim and Magnusson 2008). Costs for injuries associated with road barrier collisions are a considerable part of the socio-economic costs. To estimate such costs for a particular barrier type it is necessary to quantify the specific risks of collision and injuries associated with that barrier (Karim et al. 2010). Unfortunately, it is often difficult to precisely quantify the injury risks associated with road barrier collisions because information regarding collisions, traffic condition and road barrier types is often unavailable.

The objective of this study was to quantify and compare the rate of injury associated with collisions with different barrier types. This study is unique in that barrier performance evaluations were based on actual collision data, post-impact collision data and an injury classification made by Swedish healthcare services. It shows how road barriers actually perform.

Since the study is based on Swedish data, the conclusions can be applied to other Nordic countries where the road design is similar. However, the study’s methodology can be applied to similar studies. The results will be used in an ongoing research project to estimate accident costs as a part of the socio-economic costs in a model for calculating life-cycle costs for road barriers.

2. Literature review

Road barriers are used to prevent vehicles from veering off the roadway into oncoming traffic, crashing into solid roadside objects, or falling into ravines. Road barriers are also used to protect pedestrians and cyclists from traffic and to protect roadside obstacles. Road barriers are usually categorized as flexible, semi-rigid or rigid, depending on their deflection characteristics on impact (AASHTO 2006).

In general, the use of road barriers is a very effective way to reduce road injuries and fatalities. Installation of median cable barriers on 13 m wide roads reduced the number of fatal crashes by almost 76% in Sweden during the period 1998 – 2009 (Carlsson 2009). Fatal and disabling cross-median collisions on highways in Washington State were reduced by 75% on highways by using median cable barriers (Ray et al. 2008). Another study showed that the number of fatal collisions reported by police on French highways with roadside barriers was 50% less than on roads without barriers (Martin et al. 2001).

Despite the effectiveness of reducing injuries, road barriers themselves may cause severe or fatal injuries by inflicting severe impact forces on vehicle occupants during a crash (Road and Traffic Authority 2004; Insurance Institute for Highway Safety 2008; Stigson 2009). The severity of an impact into a road barrier depends on the barrier’s flexibility, impact angle and impact speed. Flexible systems, such as cable barriers, generally impose lower impact forces upon vehicles than other systems, since more of the impact energy is dissipated by deflection of the barrier (AASHTO 2006). Because the impact event occurs over a large lateral distance, the time of the impulse event is extended. With flexible barriers, the risk of post-impact collisions has to be considered. Thomson (1999) showed that 65% of the cases involving impacts with flexible barriers resulted in severe secondary collisions (i.e., Post-impact collisions).

Impact speed is another factor affecting impact severity. According to Singelton et al. (2004), the injury risk is proportional to impact speed. It has been shown that a higher posted speed is associated with higher crash severity (Ydenius 2009).

The severity of a barrier impact also depends on the impact angel. Based on full-scale barrier crash tests, a study showed that the impact severity increased when the impact angel increased from 20° to 45° (Ydenius 2010). The most significant increase in injury risk occurred with concrete barriers. Based on this result, flexible or semi-rigid barrier systems showed potential for reducing injury severity. It is worth noting that Ydenius did not consider the risk for severe injuries due to secondary collisions. Bryden and Fortuniewicz (1986) showed that 25% of barrier collisions resulted in secondary collisions causing severe injuries. It has also been reported that 25% of all road median barrier collisions involve more than one collision and that severity increases with the number of collisions (Mak et al. 1986). Secondary collisions have been reported as the cause of more severe injuries than the initial impact with road barriers (Ray et al. 1986; Ray et al. 1987).

Furthermore, choosing a 45° impact angle by Ydenius as an initial barrier impact angle in barrier crash tests is to some extent unrealistic. A reconstruction of 81 accidents on European roads showed that 90% of the cases had an exit angle (i.e., angle between the barrier and the travel line of the vehicle after the collision) below 20° (Thomson et al. 2006). On a straight road with a barrier parallel to the edge line, the exit angle and the impact angle are almost equal. A factor affecting the impact angle is the lateral distance between the barrier and the edge line of the carriageway. The possible impact angle increases if a longer lateral distance is available for the vehicle to travel (Thomson et al. 2006).

The lateral distance between the road barrier and edge line of the carriageway also affects the risk of post-impact over-rides and under-rides which in turn affects barrier collision severity (Marzougui and McGinnis 2010).

3. Method and material

Evaluation of barrier performance based solely on current crash test methods (European Committee for Standardization 1998) does not give an accurate result. Thomson (Thomson 1999) highlighted a conservative approach to the design and test evaluation of road barriers. He stated that impact conditions, redirection criteria and occupant response parameters in current crash tests are specified for rather unlikely crash events. He pointed out ignorance of the effects of secondary collisions, choice of too small impact angels and conflicts between approaches predicting occupant injury risks in crash tests and actual barrier performance. Therefore, the analyses in this study were based on documented data associated with actual road barrier collisions for the period 2005- 2008 in Sweden. There were several reasons for choosing that specific period. One reason was that before 2005 there were only a limited number of cable barriers in Sweden. Another reason was to avoid both the impact of road reconstructions made before 2005 and several changes in posted speed limits implemented on the studied roads after 2008.

The best way to compare road barrier performance is to use documented barrier collision data to calculate collision rates as described in NCHRP Report 490 (Ray et al. 2003). Collision rates are calculated by determining the number of collisions in a particular category and dividing it by the traffic work (i.e. vehicle kilometres travelled) along that road segment. In the present study, the analysis was based on the injury rates calculated by dividing the number of injuries in a specific injury category, by the traffic work during a four year period for the road segment equipped with a specific barrier type using the following equations:

$$IR_{bt,i} = \frac{NI_{bt,i}}{TTW_{(bt)}} \qquad (1)$$

$$TTW_{bt} = AADT_{bt} \bullet BL_{bt} \bullet NY \bullet 365 \qquad (2)$$

where

IR = Injury rate measured in number of injuries per vehicle kilometre.
NI = Number of injuries.
bt= Barrier type.
i = ISS-interval.
TTW = Total traffic work.
AADT = Average annual daily traffic.
BL = Barrier length.
NY = Number of years covered in the study.

3.1. Inventory of road barrier lengths and annual average daily traffic

The road segments studied included 640 km of road E4, located between Helsingborg and Knivsta, and 346 km of road E6, locate between Rabbalshede and Vellinge. At the beginning of the project records of the lengths of median barriers were limited and records for roadside barriers were unavailable. For this reason, the lengths of barriers along the studied roads were measured on-site. A vehicle mounted digital distance meter, Coralba Tripmeter®, was used to measure barrier length. The results were registered in MS-excel® to facilitate combinations with other parameters, such as posted speed limit and AADT on the studied roads, for further analyses (Table 1).

Information regarding AADT was obtained from a web-based database called AADT-Map containing information about Swedish roads. In this application, the Swedish road network is categorized into homogeneous sections. For each section, the traffic volume is measured regularly using temporary or permanent traffic measuring stations. AADT along the highways in Sweden is measured every fourth year and presented on digital maps or tables. To calculate AADT for the barriers and years included in this study, a 2% annual traffic increase factor was used.

Table 1. Barrier lengths and posted speed limits along the studied roads segments.

	Posted speed limits (km/hr)												
	50		70		90		100		110		120		
Barrier type	Barrier length (km)	%	Barrier length (km)	%	Barrier length (km)	%	Barrier length (km)	%	Barrier length (km)	%	Barrier length (km)	%	Total length (km)
W-beam			10	1	126	9	82	6	1001	72	168	12	1387
Cable	1	0.1	1	0.1	3	0.3	71	6.9	570	55.9	374	36.7	1020
Concrete			26	23	37	32	1	1	51	44		0	115
Pipe	0.1	0.2	22	27	8	10	0.5	0.6	42	51.2	9	11	82

3.2. Inventory of road barrier collisions

Injuries due to collisions with four barrier types were studied: concrete barriers, w-beam barriers, pipe barriers and cable barriers. Collisions with a combination of these barrier types were excluded as it was hard to conclude which barrier type contributed to the injuries. Collisions with uncommon barrier types were also excluded. Injuries due to post-impact events, e.g., post-impact collisions with barriers or other vehicles were included in the analyses. Collision data on the studied roads was obtained from the Swedish Traffic Accident Data Acquisition (STRADA) which is a coordinated national registration of traffic accidents and traffic injuries run by the police and the health care authorities. The police and the healthcare services involved collect data regarding the accident and injured persons at the accident site and in the emergency room, using different questionnaires. The data collected by the police includes how, when, and where the accident took place, traffic environment, posted speed limit, circumstances of the accident, light and road surface conditions, passive safety systems used and facts regarding the injured persons. A judgment of injury severity is also made by the police on-site. The police classify the injuries associated with traffic accidents into four categories: Fatal, severe, mild and no injuries (i.e., only property damage). At healthcare facilities, supplementary data such as diagnosis, classified according to Injury Severity Score Codes (ISS), and care are collected. ISS is an anatomical scoring system providing an overall score for patients with multiple injuries. Each injury is assigned an Abbreviated Injury Scale (AIS) score, allocated to one of six body regions (head, face, chest, abdomen, extremities, and external). Only the highest AIS score in each body region is used. The three most severely injured body regions have their score squared and added together to produce the ISS score. Healthcare services classify injuries associated with traffic accidents in five ISS-intervals: 0 (unhurt), 1-3 (mild injury), 4-8 (moderate injury), 9-16 (severe injury) and 16- (very severe or fatal injury). In this study, each collision was carefully evaluated to collect the following information from STRADA: location of the collision, posted speed limit where the collision occurred, number of persons involved, injury type, barrier type, barrier location (median barrier or roadside barrier), cause of the collision, and how the vehicles involved behaved during and after the collision.

Traffic safety analyses in Sweden are often based on accidents reported by the police because the number of accidents reported by healthcare services is limited due to limited number of the healthcare services connected to STRADA. It is well-known that injury classifications made by police are less accurate than classifications made by the healthcare services as the police have neither the qualifications nor the required tools to make diagnoses on-site. The miss-classification of injuries by the police depends on the reporting police force, injury severity, victim's age and type of road user (Amoros et al. 2007). To minimize the possible effect of this miss-classification on this study, the injury classification made by healthcare services was used as a basis for analyses. Furthermore, the number of injuries in different categories reported only by the police was converted to the number of injuries in ISS-intervals, using the percentages of observed differences for injuries reported by both parties. The number of injuries for each converted ISS-interval was later summarized with the number of injuries reported only by healthcare services for the same ISS-interval. This result was used in equation 1 to calculate the injury rate for each ISS-interval.

3.3. Statistical Analyses

For the statistical analysis, a method called Poisson regression analysis was used. In this case the logarithm of the expected injury rate for a specific severity class is assumed to have a linear regression on barrier type and posted speed limit, where barrier type and speed limit are quantified by sets of dummy variables and the logarithm of vehicle mileage is an offset variable, i.e. the regression coefficient is fixed at one. The linear regression equation is expressed as follow:

$$\log IR = A + B_1 \bullet I_{cable} + B_2 \bullet I_{w-beam} + B_3 \bullet I_{concrete} + C_1 \bullet I_{70km/hr} + C_2 \bullet I_{90km/hr} + C_3 \bullet I_{110km/hr}$$

(3)

where

I = dummy variables with value 1 if the condition, i.e. barrier type or speed limit according to subscript, is fulfilled and zero otherwise.

A, B and C = regression coefficients estimated by standard methods (McCullagh and Nelder 1989).

The speed limit can be considered as a proxy for the circumstances that determine the general road safety standard, e.g. traffic volume, road alignment etc. That is the reason for including speed limit in the equation; otherwise, the injury ratios for the different barrier types might contradict the circumstances determining the speed limit.

The assumption that the number of injuries has a Poisson distribution might not be fully valid. Several injuries might occur in the same accident and will therefore not be statistically independent, which is a violation of the Poisson assumption. In that case, the data will be over-dispersed. When over-dispersions were detected using the deviance, adjustments according to the Quasi-likelihood method were made, as suggested by McCullagh and Nelder (1989). According to that method, the likelihood ratio test statistics is divided by the ratio of the deviance and the degrees of freedom. Then the p-value will be higher than without the adjustment. Also, the number of injuries for each data becomes larger resulting in a more powerful statistical inference. When the statistical inference shows different injury rates among the barrier types a post-hoc analysis is done, where barrier types are merged together if the injury rates are not significantly different. The procedure is continued stepwise until no more merging is possible. Road accident data are often analyzed according to severity classes where all injuries above a certain severity level are included, e.g. fatalities, fatalities and serious injuries or fatalities and all injuries. In this case, the severity is shown by the ISS-level. Then it was reasonable to analyze data in a similar way, i.e. the number of injuries above a certain ISS-level.

In STRADA, 1019 barrier collisions, involving 1529 persons, were found along the studied roads during the period 2005-2008 (Table 2). Among the collisions studied, 330 collisions, involving 495 persons, were reported both by police and healthcare services.

Table 2. Traffic work and injuries associated with barrier collisions for the period 2005-2008

Barrier type	Traffic work 2005-2008 (100 Mvkm)	Injury classification made by the Police: No injuries	Mild injuries	Severe injuries	Fatal injuries	Injury classification made by the healthcare services (ISS-intervals): 0	1-3	4-8	9-15	16-
		Number of injuries								
W-beam	321.38	73	476	96	11	73	226	30	5	13
Cable	137.78	33	406	22	4	112	173	14	7	6
Concrete	41.57	12	67	9	0	4	41	1	1	0
Pipe	25.99	9	59	15	0	5	17	2	2	0
Sum	526.74	127	1008	142	15	194	457	47	15	19

Table 3 shows an over-classification of injury severity made by the police in Sweden. For example, among the injuries classified as severe by the police only 15% were in fact injuries with ISS $\geq$ 9. To minimize the possible effect of this miss-classification on this study, the injury classification made by healthcare services was used as a basis for analyses. Furthermore, for accidents reported solely by the police (Table 4), the injury categories were converted to ISS-intervals (Table 5) using the percentages of observed differences for injuries reported by both parties (Table 3). An example of the conversion is given in Table 5. Later the number of injuries under the same ISS-intervals in Tables 1 and 4 were summarized as shown in Table 6.

Table 3. Number of injuries in the same injury categories respectively ISS-intervals for those barrier collisions reported both by police and healthcare services

ISS-Interval	Injury categories: No injuries: Injuries	%	Mild injured: Injuries	%	Severe injured: Injuries	%	Fatal injured: Injuries	%	Sum: Injuries	%
0	9	50	88	21.95	4	6.45	0		101	20.40
1 - 3	9	50	279	69.58	35	56.45	0		323	65.25
4 - 8	0		25	6.23	14	22.58	0		39	7.88
9 - 15	0		7	1.75	6	9.68	0		13	2.63
16 -	0		2	0.50	3	4.84	14	100	19	3.84
Sum	18	100	401	100	62	100	14	100	495	100

Table 4. Number of injuries associated with barrier collisions reported only by police

Barrier type	Injury category: No injuries	Mild injuries	Severe injuries	Fatal injuries
W-beam	63	300	56	0
Cable	28	221	9	0
Concrete	10	41	4	0
Pipe	8	45	11	0
Sum	109	607	80	0

Table 5. Number of injuries associated with barrier collisions reported only by police converted to ISS-intervals

Barrier type	ISS-interval 0	1 - 3	4 - 8	9 - 15	16 -
W-beam [a]	101	272	31	11	4
Cable	63	173	16	5	2
Concrete	14	36	3	1	0
Pipe	15	42	5	2	1
Sum	193	522	56	18	7

[a] For w-beam barriers the number of injuries with ISS zero = $63 \cdot 50\% + 300 \cdot 21.95\% + 56 \cdot 6.45\% = 101$

Table 6. Number of injuries associated with barrier collisions reported both by police and healthcare services after conversion

Barrier type	ISS-interval 0	1 - 3	4 - 8	9 - 15	16 -
W-beam	174	498	61	16	17
Cable	175	346	30	12	8
Concrete	18	77	4	2	0
Pipe	20	59	7	4	1
Sum	387	979	103	34	26

For injuries with ISS ≥ 1, a likelihood ratio test showed that the differences in injury rates between the barrier types were significant ($p < 0.001$) (Table 7). In this case, the goodness of fit ratio (i.e., deviance divided by the degrees of freedom) was 2.4 and therefore over-dispersion was assumed. For injuries with ISS≥1, the Post-hoc analysis shows that cable barriers, at a 95% confidence interval, have 48 - 127% higher injury rates than other barrier types. For injuries with ISS ≥ 1, the analysis showed significant differences between the injury rates for different posted speed limits ($p < 0.001$). The highest injury rate indicated on roads with speed limit of 90 km/hr (Table 7).

Table 7. Injury rates and confidence intervals for injuries associated with barrier collisions

	Injuries with ISS ≥ 1		Injuries with ISS ≥ 4		Injuries with ISS ≥ 9	
	Injury rate [a]	Confidence interval (95%)	Injury rate	Confidence interval (95%)	Injury rate	Confidence interval (95%)
Barrier type						
W-beam	2.09	1.77 - 2.47	0.29	0.21 - 0.39	0.11	0.07 - 0.17
Cable	3.82	3.10 - 4.69	0.41	0.27 - 0.60	0.19	0.11 - 0.31
Concrete	1.75	1.22 - 2.52	0.14	0.06 - 0.32	0.04	0.01 - 0.15
Pipe	2.44	1.59 - 3.72	0.39	0.19 - 0.81	0.07	0.02 - 0.31
Posted speed limits (km/hr)						
70	2.83	2.21 – 3.62	0.29	0.18 - 0.47	0.09	0.04 - 0.21
90	3.63	2.75 - 4.77	0.53	0.33 - 0.85	0.17	0.07 - 0.39
110	1.81	1.48 - 2.20	0.25	0.18 - 0.36	0.07	0.03 - 0.13
120	1.84	1.18 – 2.88	0.17	0.07 - 0.43	0.08	0.02 - 0.29

a The injury rates are presented in number of injuries per 100 million vehicle kilometre.

For injuries with ISS ≥ 4, the differences in injury rates between barrier types were also statistically significant ($p = 0.041$) (Table 7). In this case, the goodness of fit ratio was 1.0 and therefore over-dispersion was not assumed. For injuries with ISS ≥ 4, the post-hoc analysis shows that concrete barriers, at 95% confidence interval, have a 5 - 81% lower injury rate than the other barrier types. For injuries with ISS ≥ 4, the differences in injury rates between different posted speed limits were also significant ($p = 0.013$). The highest injury rate was indicated on 90 km/hr roads. For the injuries with ISS ≥ 9, the statistical analysis for the differences in injury rates between barrier types and speed limits were not statistically significant ($p = 0.208$). A limited number of barrier injuries with ISS ≥ 9 can be an explanation.

4. Discussion

4.1. Effect of barrier types

The results show that the rate of injuries with ISS ≥ 1 and ISS ≥ 4 was higher due to collisions with cable barriers than with other barrier types (Table 7). The second and the third highest injury rate were associated with pipe and w-beam barrier collisions, respectively. The lowest injury rate was observed with concrete barriers collision. As an explanation for the high rate of injuries due to collision with pipe barriers, it is worth noting that 70% of the pipe barrier collisions presented in this study were collisions with pipe barriers installed along highway bridges in urban regions with high traffic density, several connecting roads, and, consequently, a higher risk for barrier collisions and post-impact collisions. Furthermore, pipe barriers along bridges are distinguished by a strong construction due to its solid posts and additional longitudinal beams. Even though this type of pipe barrier constituted only 34% of the total studied pipe barrier length, collisions with them resulted in 75% of the injuries reported. It is also known that the pipe-beams often do not interact during the impact event due to a weak connection between them. The lower pipe-beam often falls to the ground during the impact (Lennart Wahlund, personal communication, 25 Oct. 2010). These facts might to some extent explain the high injury rate associated with pipe barrier collisions. To find more explanations for the differences in injury rates between the studied barrier types, several post-impact events were studied. As for any automobile accident, barrier collisions are divided into three phases: Pre-impact, impact and post-impact. Post-impact events include all events that can occur during the post impact phase. It should be observed that one or several events can occur during the post-impact phase. In this study the following post-impact events have been studied:

- Post-impact collisions, where the vehicle after the initial barrier collisions smashes into other vehicles, barriers or other obstacles.
- Redirection of vehicles, where the vehicle has crossed more than one lane after the initial barrier collision.
- Post-impact over-rides or under-rides, where the vehicle rides over or under a barrier
- Post-impact roll-overs, where the vehicle turns over after the initial barrier collision or after a post impact collision.

The above mentioned post-impact events are discussed more in details below

4.1.1. Post-impact collision

The rates of barrier collisions resulting in post-impact collisions were to some extend higher on roads equipped with cable barriers and pipe barrier than with the other barrier types (Table 8). This could be a possible explanation for the differences in the injury rates between the barrier types. As mentioned before, post-impact collisions cause more severe injuries than the initial impact with road barriers (Ray et al. 1986; Ray et al. 1987). It is also known that severity increases with the number of collisions (Mak et al. 1986).

Table 8. Post-impact events occurred immediately after the first impact.

	Barrier collisions resulting in post-impact collisions		Barrier collisions where the redirected vehicle crossed more than one lane		Barrier collisions resulting in post-impact over-rides		Barrier collisions resulting in post-impact roll-over	
Barrier Type	Number of collisions	Rate [a]	Number of collisions	Rate	Number of collisions	Rate	Number of collisions	Rate
W-beam	45	0.14	94	0.29	7	0.04	48	0.15
Cable	25	0.18	73	0.50	19	0.14	47	0.34
Concrete	6	0.15	18	0.38	0	0	2	0.05
Pipe [b]	4	0.17	12	0.46	-	-	4	0.15

[a] Collision rates are presented in number of collisions per 100 million vehicle kilometre
[b] Pipe barriers did not exist as road median barriers along the studied road.

The high rate of post-impact collisions along roads equipped with cable barriers could be due to the fact that median cable barriers in Sweden are often placed at the centre of the road median. With this placement, barrier collisions will occur with large impact angles and, consequently, large exit angles. Large exit angles normally increase the risk for post-impact collisions. On the other hand, w-beam and concrete barriers are often installed very close to the edge line of the carriageway. This way of placement contributes to small impact angles, and, consequently, small exit angles. Ydenius (2010) confirmed that the post-impact exit angles increased drastically for semi-rigid and flexible barriers when impact angles increased from 20° to 45°, while it remained almost the same for rigid systems.

4.1.2. Redirection of vehicles

After a barrier collision, the vehicle involved is almost always redirected. However, redirection occurs at different angels and along different lateral distances. In this study, the analysis of vehicle redirection events focused on barrier collisions where the vehicle involved crossed over more than one lane after being redirected back into traffic. This is because the longer the lateral distance, the higher the risk for other post-impact events.

Table 8 shows that the rate of barrier collisions, where the vehicles after impact crossed more than one lane, was highest on roads with cable and pipe barriers. This indicates that the vehicle travelled a long lateral distance after impact with cable or pipe barriers. This contributes to an increased risk for post-impact collisions. A combination of the cable barrier's flexibility and mechanical properties as well as driver behavior might be an explanation for long lateral travel distances. Unlike other barrier types, cable barriers generally impose low impact forces on vehicles because the impact energy is dissipated by barrier deflection (AASHTO 2006). It is therefore possible that the steering systems often remain undamaged after a cable barrier collision. This allows the driver to instinctively redirect the vehicle back into traffic after the impact. Cable elasticity could impose an additional force, propelling the vehicle back into traffic. Consequently, the risk of post-impact collisions and post-impact roll-overs will increase. In collisions with rigid or semi rigid barriers, deflection and elasticity is limited and vehicle damage is usually so extensive that the drivers cannot steer the vehicle after the impact, and the vehicle will only travel a short distance. This could explain the low rate of post-impact events caused by concrete and w-beam barriers (Table 8). Unfortunately, no scientific research confirming this has been found.

4.1.3. Post impact over-/under-rides

The collision rate for vehicles ending up in the opposite traffic lanes, due to over-/under-rides, was highest for cable barriers (Table 8). This high rate of over-/under-rides could be an explanation for the high injury rate observed on roads equipped with cable barriers. One explanation for the high rate of over-/under-rides observed on roads equipped with cable barriers could be the placement of cable barriers. As mentioned before, cable barriers in Sweden are placed at the centre of the road median, while w-beam and concrete barriers are placed close to the edge line of the carriageway. Consequently, the impact angles will be larger on roads equipped with cable barrier than on roads equipped with w-beam and concrete barriers. A combination of high speed and large impact angle might increase the risk for over-/under-rides. According to Marzougui and McGinnis (2010), placement of barriers at the road median centre or close to it increases the risk for over-/under-rides. Another disadvantage of the placement of barriers at the centre of the road median is that the snow heaps on the edges increase the risk for over-rides by decreasing the required height of median barriers. Several incidents of this type were observed in Sweden during the last years. It is also worth noting that w-beam barriers in Sweden are often installed on both sides of the road median. This double installation reduces the risk of the errant vehicle crossing the road median. Over-/under-rides due to collisions with concrete barriers were not found in this study. It is worth noting that heavy trucks were not involved in any of the over-rides.

4.1.4. Post-impact roll-overs

The highest rate of post-impact roll-overs occurred in collisions with cable barriers (Table 8). This high rate of roll-overs could partly be explained by the high rate of post-impact over-rides for cable barriers. The instinctive reaction of the drivers to redirect the vehicle after the impact might also increase the risk for roll-overs.

4.2. Effect of posted speed Limits

The injury rate associated with barrier collisions, with ISS≥ 1 and ISS ≥ 4, respectively, was higher on roads with speed limits of 70 and 90 km/hr than road with speed limits of 110 and 120 km/hr. This result is in contrast a studies presented by Singelton et al. (2004) which showed that the injury risk was proportional to impact speed. To explain this divergence, it is worth noting that the roads with speed limits of 110 and 120 km/hr investigated in this study were mainly rural roads with high geometrical standard, such as smooth alignment, and good visibility. Whereas, roads with posted speed limits of 70 and 90 km/hr were mainly urban roads with high traffic density, several connecting roads and, consequently, a higher barrier collision risk, as Karim et al. (2010) showed. The effect of posted speed limits on injury rates for each specific barrier type could not be investigated because separating data in this way gave an insignificant basis for statistical analysis.

4.3. Limitation and strength of the study

The high injury rate for cable barriers found in the present study is in contrast to the results of previous studies and the good reputation that cable barriers have (AASHTO 2006; Ray et al. 2008; Ydenius 2010). This divergence could be due to the use of injury classifications made by healthcare services and the consideration of injuries associated with post-impact events in the present study.

The effect of non-reported traffic accidents on the accuracy of traffic safety analyses is a well-known issue (Elvik and Mysen 1999; Amoros et al. 2005). A comparison between results of the present study and results of a study of barrier repairs on the studied roads during 2006 (Karim et al. 2010) showed that the number of reported barrier collisions in STRADA was only 17-31% of the number of reported barrier repairs, depending on the geographical region. The rate of reporting is usually highest for accidents involving fatal injuries, and lowest for accidents involving only property damage (Amoros et al. 2005), and, therefore, collisions with ISS = 0 were not considered in the analysis in this study.

Each barrier type investigated in this study exists in many different designs. Even though this variation might affect the results, it was not considered in this study because segregation of variants would give an insignificant basis for statistical analyses. Collisions with more than one barrier type were excluded in this study as it was hard to conclude which barrier type contributed to the injuries.

5. Conclusions and recommendations

Based on the results presented in this study, the following conclusions can be drawn:

- The rate of injuries associated with barrier collisions in Sweden is higher on roads equipped with cable barriers than on roads equipped with other barrier types.
- The rate of barrier collisions resulting in post-impact collisions, over-rides, roll-overs and collisions, where the vehicle crossed more than one lane after the initial barrier collision, is higher on roads equipped with cable barriers than on roads equipped with other barrier types. This high rate of post-impact events associated with cable barrier collisions is probably due to the placement of cable barriers and their mechanical properties.
- The result of this study contrasts with previous evaluations which indicated a higher performance level for cable barriers compared to other barrier types. This divergence might be explained by the use of actual documented collision data, consideration of injuries associated with post-impact events, and use of injury classifications made by healthcare services in this study.
- The injury rate associated with barrier collisions is higher on roads with speed limits of 70 and 90 km/hr than on roads with speed limits of 110 and 120 km/hr.

In order to re-evaluate the Swedish guidelines for placement of the median barriers, SRA is recommended to investigate the high rate of over-/under-rides and roll-overs due to collisions with cable barriers. SRA is also encouraged to use the injury classification system used by healthcare services for future barrier performance evaluations and other traffic safety analyses. For this reason, reporting injuries by healthcare services on a nationwide level is required.

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